From a Planned Action to a Revised Action:
Revealing the Structure of Motor Plans

By

Katie Lawless
B.A., University of Victoria, 2016

A Thesis Submitted in Partial Fulfillment of the Requirements for the degree of

MASTER OF SCIENCE

In the Department of Psychology

Supervisory Committee

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Abstract

We examined the effect of changing from an internally prepared motor plan to a revised action which potentially differed from the original plan along two dimensions: wrist orientation (horizontal or vertical) and left/right hand. Participants were instructed to prepare a particular hand grasp action and then were cued either to execute that motor plan or cancel it and plan a new action. In Experiments I and II, if the change from the original motor plan to an alternate response implied an action different from the prepared one, there was a slowing in response time. Moreover, if there was a change, maintaining the originally planned wrist orientation produced faster responses than changing orientation, but only if the response hand remained constant between planned and alternate actions and the cue was an image of a hand depicting a goal posture. In Experiment III, when the alternate action was cued by an image of an object inviting a particular grasp action, there was transfer only of the hand feature. In a final experiment, participants switched from a prepared action to naming a manipulable object. The motor features of the object differed from the original motor plan in the same way as in previous experiments. No effect of the previously cancelled motor plan was seen on naming latencies. These results elucidate the nature of motor plans and the role of motor actions in the representation of objects.

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Introduction

We live in a dynamic world where information about the environment quickly changes. This change may demand the termination of one motor plan while smoothly and efficiently cueing another. Something as simple as deciding to pick up a knife can afford a number of motor plans. You may decide to pick up a knife with a power grasp, but on the basis of further information, say that the knife is dirty, you quickly change to lift the object with a precision grip. Given the idea that an object has competing affordances that are automatically evoked, we can think of action reprogramming as follows: one action is selected based on attention, followed by a change that requires the initial action to be suppressed and another motor affordance to be potentiated. Our interest is specifically in the relationship between the sequence of events that take place when people cancel a motor plan before execution, and develop a new motor plan. The features of the action (hand and orientation) are of importance and this thesis will present more information about the structure of a motor plan and its ability to transfer into a new motor plan involving these features.

Of crucial importance to reprogramming a motor plan is the ability to override the original intention (Bestmann & Duque, 2015). A substantial amount of research has been done on the inhibition of a motor plan. However, this work has mostly relied on the stop-signal paradigm to halt action without requiring a switch to a new motor plan. Experiments that rely on motor evoked potentials (MEP) in the stop-signal paradigm provide evidence that suppression works rather globally, suppressing motor potentials far removed from the effectors involved in the planned action (Bestmann & Duque, 2015).

Our interest lies in the mechanisms that allow the termination of a current plan while smoothly and efficiently cueing another. Unlike the extensive work on stopping, there is little theoretical or behavioural work that clarifies how motor plans are halted and reprogrammed to produce a new action. Relevant to this question is research on switching between actions after the motor plan is carried to completion. What motor features remain available after an action is completed and a new one, sharing some of these features, is produced? Indeed, evidence clearly indicates that the motor system has the ability to conscript features of a previously executed motor plan as part of a new action.

Jax and Rosenbaum (2007) found that during a task requiring participants to move a dowel, on some trials, around an obstacle to a target, the curvature of the trajectory transferred to ensuing actions, even when these actions involved the opposite hand. Schütz and Schack (2015) asked whether transfer would be found in motor plans for hand posture in a task requiring the use of the left and right hand to open drawers in ascending and descending order. When participants changed hands, they were also required to change body position to be either on the left or right side of the drawers. The results showed that there was a motor hysteresis effect before the hand switch, but not after, suggesting that there is reuse of the motor plan within the same hand, but not between hands (Schütz & Schack, 2015). Valyear and Frey (2014) found similar results when tasking participants with grasping and placing objects using either their left or right hand. Valyear and Frey (2014) concluded that grasps are computed independently per hand, and that their results support hand-specific levels of grasp representations. From these results, it is clear that transfer of features between hand actions depends on task demands.

The results showing that features of motor plans from completed actions can transfer to a new motor plan evokes a query of whether these features can transfer when the original motor plan is cancelled before execution. Consider the following task. On 20% of trials, participants were instructed to carry out an action they had prepared, cued by a green dot. The remaining

80% of trials required action reprogramming; participants had to cancel their motor plan and change to a new one indicated by an image of a hand cue denoting a new grasp. Response times were measured to observe the switch costs. In Experiment I, two response elements were used, each consisting of a vertical bar with a horizontal bar protruding into the left or right side of space. The element with the left protrusion was used for left-handed responses, and the element with the right protrusion was used for right handed responses. Experiment II was a replication of the above, with only one response element located centrally for both hands. Given previous evidence that extrinsic target coordinates play a role in transferring features of motor plans (Schütz & Schack, 2015), we might expect no transfer between hands in Experiment I (where two response elements are presented in separate locations). In Experiment II, we used a single response element, so some transfer might occur between hands.

The images of the hands used to cue the changed action in Experiments I and II depicted goal postures. Rosenbaum, Cohen, Jax, van der Wel, and Weiss (2007) have emphasized the importance of this representation in action planning. Research has shown that images of hands displayed in an egocentric viewpoint have special properties in that these images activate regions in the brain closely tied to the preparation and execution of a reach and grasp action (Mahon, 2013). The goal posture shown by a hand image is a relatively direct representation of a hand action. Functional neuroimaging has also shown that motor cortical regions are active when viewing images of graspable objects (Martin, Haxby, Lalonde, Wiggs & Ungerleider, 1995; Martin, Wiggs, Ungerleider & Haxby, 1996). Our task design enables us to explore the question of whether a motor plan affects the execution of a new motor plan evoked by an object in the same way as an action cued by the depiction of a grasp posture. If these action representations are the same then we would expect to see comparable results. Accordingly, Experiment III was designed to clarify the nature of motor representations in switching from a planned action to a new action, cued by the image of a handled object affording a particular grasp. The experiment was a replication of Experiment II, with the exception that the goal posture was replaced by the image of a handled object. The objects chosen for Experiment III afforded the same grasps as the hand cue, but whether they evoke the same motor representations remains to be determined.

The first three experiments involved observing how actions are affected by the features of a cancelled motor plan. This enterprise raises further questions, including how other tasks, such as naming graspable objects, are influenced by components of a previously cancelled motor plan. Evidence suggests that motor representations are implicated in the naming of graspable objects. Yee, Chrysikou, Hoffman, and Thompson-Schill, (2013) found that accuracy rates in naming objects that are frequently touched were affected by the concurrent execution of a motor task. In addition, Witt, Kemmerer, Linkenauger, and Culham, (2010), required participants to squeeze a ball while classifying pictures as animals or tools. Responses to tools were slower when the handle of the object was aligned with the hand grasping the ball. Further evidence that motor representations can play a role in object naming was obtained Bub, Masson, and Lin (2013). Participants were required to hold a motor plan in working memory cued by image of goal postures similar to those used here. While these motor representations were actively maintained for later recall, participants were required to name a handle object. The results provided further evidence that motor features in working memory can affect the ability to name an object associated with actions that incorporate these features. To obtain further insight into the relationship between the constituents of a planned action and the naming of a graspable object it was of interest to replicate Experiment III, but with the requirement to name the object instead of acting out the grasp it affords. We hypothesize that there will be some influence on naming time of the overlap in action features between a planned action and a named object. The results that we obtain from Experiments III and IV should support a coherent account of the potentially different motor representations of objects and planned actions.

Experiment I

In Experiment I, participants prepared a reach-and-grasp action denoted by a letter cue code, and then a second cue prompted them either to carry out the prepared motor plan or to cancel that plan and execute an action cued by a pictured hand. Of primary concern in this experiment was execution of the action indicated by the hand cue. In particular, we were interested in the modulation of response execution time by action features shared between the planned and the newly cued actions.

Method

Participants: 35 students (25 female; median age = 19 years) at the University of Victoria participated in the experiment to earn extra credit in an undergraduate psychology class. All participants were right handed. Prior to beginning the experiment all participants provided written informed consent and were given instructions on the task. The experiment was approved by the University of Victoria Human Research Ethics Committee.

Materials: There were two dimensions manipulated in this experiment: wrist orientation and hand. Each dimension could be manipulated in two ways, thus, there were four possible grasps. Four letter cues and four grayscale images of hands mapped onto these hand grasps (see Figure 1). For the letter cue "L" and "R" were used to represent the left and right hand, and the letters "V" and "H" represented a vertical and horizontal wrist orientation, respectively. The letters were combined to represent four grasps. “LV” represented a left vertical grasp, “LH” represented a left horizontal grasp, “RH” represented a right horizontal grasp, and “RV" represented a right vertical grasp (see Figure 1). A grayscale digital photograph was taken of a male right hand formed in a closed-gripped grasp with either a horizontally orientated wrist or a vertically oriented wrist. Both photos were mirror reversed to render left-handed poses to insure no difference in stimuli that was hand dependent.

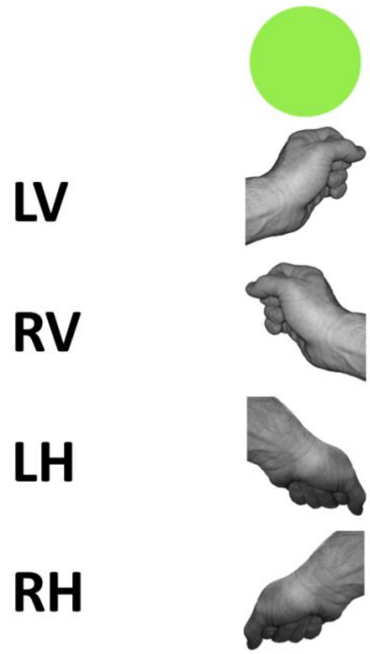

Figure 1. Letter, green dot, and hand cue stimuli used for Experiment I.

A response box (see Figure 2), with six white buttons was placed in front of participants, and they were instructed to start the trial by placing their two index fingers on the two outermost buttons. Two response elements were used (see Figure 2), each consisting of a vertical bar with a horizontal bar protruding in to the left or right side of space. Participants used these elements to produce grasp actions on to that corresponded to the stimuli presented on the screen (see Bub, Masson, & Cree, 2008, for a detailed explanation of the response device). If participants were cued to use their left hand, the leftmost element (with the left horizontal protrusion) was the target response element. The rightmost element (with the right horizontal protrusion) was the target for right-handed responses. When participants were cued to make a horizontal grasp, they were instructed to produce a grasp on the horizontal bar of the appropriate element, and if the cue indicated a vertical grasp they were to grasp the vertical bar.

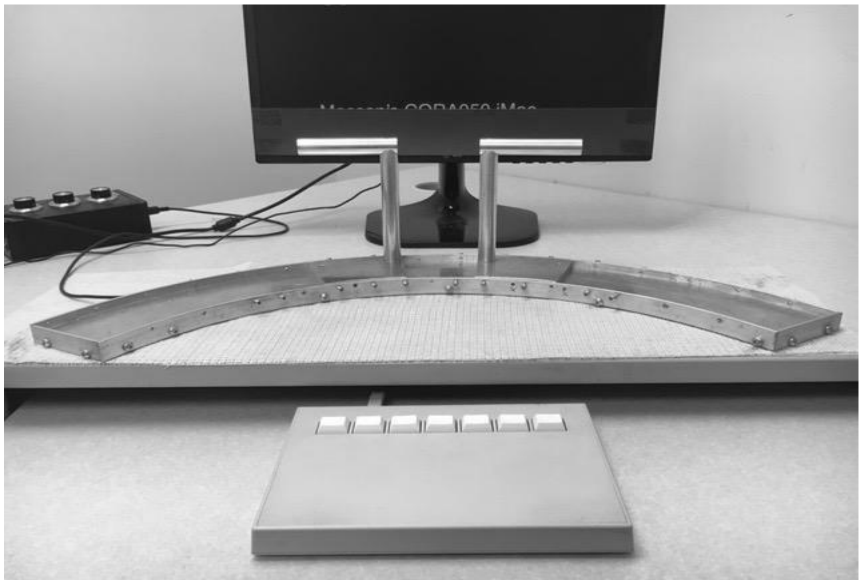

Figure 2. Response device with response elements for Experiment I.

Design: On critical trials an initial letter cue prompted the participants to prepare to execute the corresponding action. The second cue was either a green dot indicating that the participant should carry out the prepared letter cue action, or a hand cue indicating the participant should perform the grasp afforded by the hand cue instead of what they had originally prepared. A letter cue followed by a green dot accounted for 20% of the critical trials and the remaining 80% of trials consisted of a letter cue followed by a hand cue. The green-dot trials required participants to carry out letter cue action they had prepared. On the trials that required a switch from the prepared letter cue grasp to an action cued by an image of the hand, the hand cue could require the same hand grasp as the prepared letter cue or differ by either hand, orientation, or both features. This was a 2x2 factorial design wherein the hand could stay the same or change, and the orientation could stay the same or change, from the original letter-cued motor plan to the motor plan cued by the hand cue.

There were 24 practice trials of the letter cues as well as a block of 24 practice trials for the hand cues, and 20 practice trials that mirrored the critical trials. The practice block consisted of 16 hand cues and 4 green-dot trials. The participants then moved on to the critical trials. There were 400 critical trials, with a break every 40 trials which created 10 blocks. Within each block, 8 trials were green-dot trials, and the remaining 32 were equally divided among the other types of possible letter cue/hand cue combinations. Therefore, the participant saw the same amount of trials for each type of change. In total, there were 80 green-dot critical trials for each participant, and 80 trials for each switch condition.

Procedure: Participants were tested individually using a G3 Macintosh computer during a one-hour scheduled appointment. The experiment began with 24 practice trials of each cue type to ensure participants understood the letter- and hand-cue representations. Participants were given instructions at each new training and experimental phase. Each participant was first trained to prepare and execute actions associated with the letter cues. In learning the letter cues, the participant initiated the first trial by pushing down the two outermost buttons of the response box with his/her left and right index fingers, which triggered a letter cue to appear on the centre of the screen after a 500ms delay. After the participant completed the action, he/she was instructed to return his/her hands back to the button box and push down on the keys to start a new trial. When the participant returned to the keys, the experimenter would mark the response as correct, incorrect, or spoil, which would cue a 500ms delay before another letter cue appeared on the screen. To promote internal preparation of the letter cues, participants were allowed to view the letter cues for as long as they deemed sufficient. Once the participant felt he/she had prepared the letter cue as much as possible, he/she would indicate they were ready by lifting the finger of the primed hand off of the button and then pushing the button back down. This would cue a blank screen for 500-ms or 750-ms that varied randomly across trials and then a green dot would appear on the screen until key liftoff, indicating the participant should make the prepared letter-cued action on the response element. The participant would then return his/her hand back to the button to begin a new trial and the experimenter would score the trial as correct, incorrect, or as a spoiled trial on the Mac keyboard to cue a 500ms delay before the start a new trial. A response was classified as incorrect if the participant began by lifting the wrong hand or if the final executed action was incorrect. A response was considered a spoil if the participant lifted off the button before the green dot appeared, a participant did not complete an action, or that the experimenter made an error in starting the trial before the participant was ready. To promote action preparation during the time the letter cues were visible, an 800-ms response deadline was present on green dot trials. If the participant's response time was slower than the set deadline, "too slow" appeared on the screen, and a reminder to prepare the letter cue as much as possible was given verbally by the experimenter. Participants were told that this was in place as an indication to spend more time preparing the letter cue. There was a 500-ms blank delay after the experimenter coded the trial as correct, incorrect, or spoil, and then a new letter cue would appear. There were 24 letter cue training trials where the participants saw the four cues six times.

The participants were then trained for 24 trials on the grayscale hand images. As with the letter-cue practice, participants pushed down the outermost buttons to trigger a hand cue to appear on the screen. Instead of preparing the action as with the letter cues, as soon as the participant recognized the hand cue they would make the indicated grasp on the response element, and then return the hand to the button to start a new trial. The experimenter classified the response and then there was a 500-ms delay after which the next trial began.

A practice block of the critical experiment was then provided. Again, participants pressed down the two outermost buttons indicating they were ready to start the trial. Following the trigger of the trial, a letter cue would appear on the screen and participants were to prepare to make the action and then indicated that they were prepared by lifting off the finger of the hand primed by the letter cue and replacing it on the button. There was a randomly varied 500-ms or 750-ms blank delay until participants saw either a green dot, which indicated that they should make the grasp on the element that corresponded to the letter-cued action they prepared, or a hand cue would appear which indicated that they should stop what they had prepared and instead perform the grasp corresponding to the hand cue (see Figure 3 for an example). Once a grasp had been made on the element participants, would return the finger back to the button and the experiment would mark trial accuracy. This was followed by a 500-ms inter-trial interval. As with the first practice session, an 800-ms deadline was present on the green-dot trials, as well as a 1400-ms deadline on the hand cue response trials (to account for the time needed to translate the hand cue into an action). There was a deadline placed on the hand cue responses so that there was no bias to respond as quickly as possible on the green-dot trials but not on the hand cue trials. The deadlines were used only for feedback and response times longer than the set deadlines were accept in our analyses. After this final practice block, participants began the critical trials, which were an exact replication of the last practice block but with a total of 400 trials.

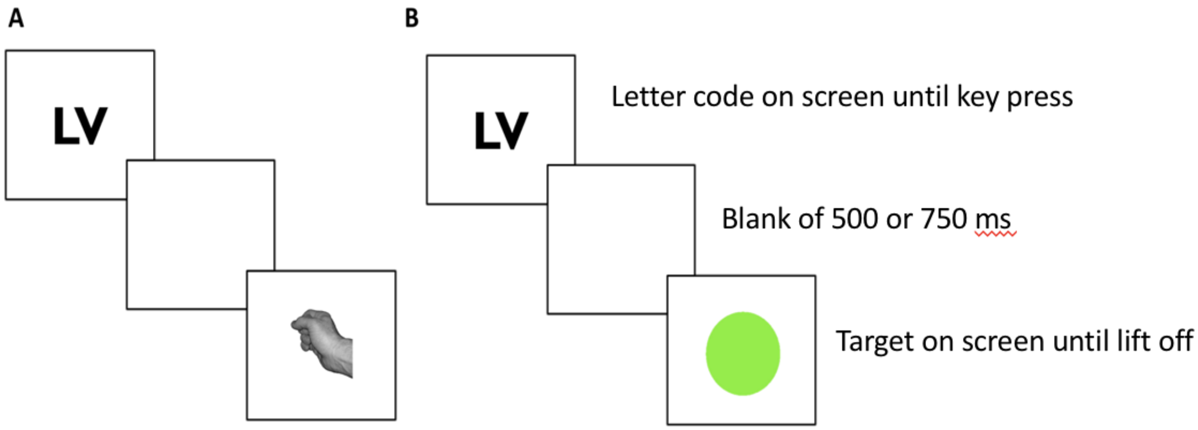

Figure 3. A) Example trial where a cancellation of a motor plan and execution of a new plan was required. B) An example green-dot trial.

Results

Three participants were excluded from the analyses because of an error rate higher than 15% on the green-dot trials. Two additional participants were excluded from the analyses because of experimenter error. Data for the remaining 30 subjects were included in the analyses. Response times were measured from the onset of the green dot or the hand cue to contact with the response element. Response times that were shorter than 100 ms or exceeded 1,800 ms were excluded from the analyses. The upper cut-off was established so that no more than 0.5% (0.47%) of the correct responses were excluded (Ulrich & Miller, 1994). For each participant, the mean correct response time in each condition was computed. On the green-dot trials the mean response time was 746 ms (74.6% of trials were completed before the deadline). This average was much shorter than any of the switch conditions, indicating that participants had prepared the originally cued action. Figure 4 illustrates mean response times for each switch condition.

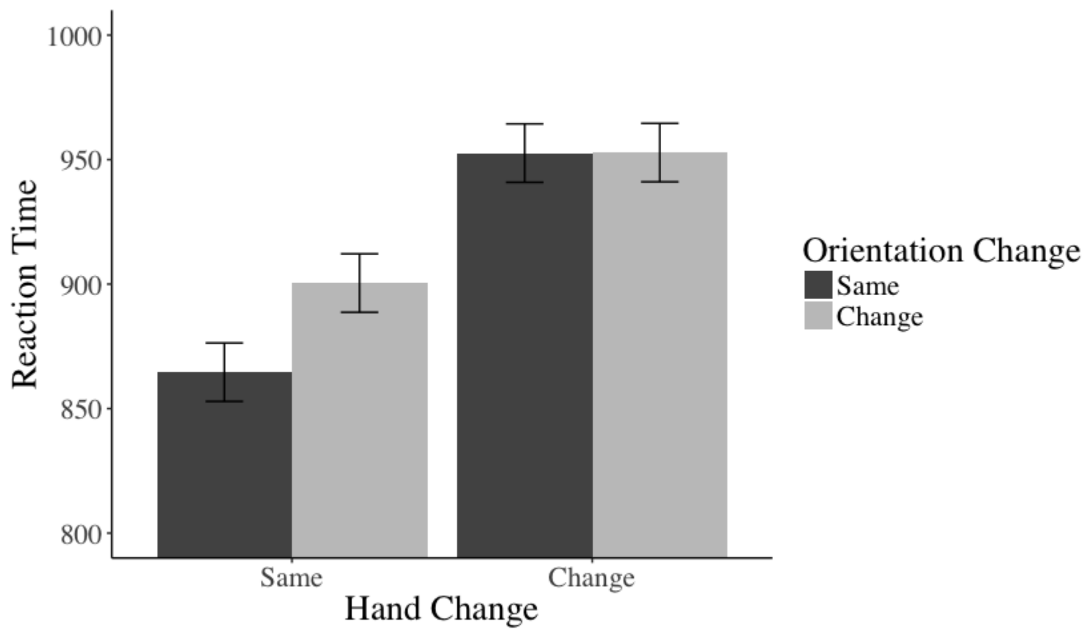

Figure 4. Response time as a function of orientation and hand change. Error bars represent 95% within-subject confidence intervals.

The effects of changing hand and orientation were evaluated by computing a Bayesian analysis which involved generating a Bayes factor to test each possible effect. Using the BayesFactor package in R, we computed 100,000 iterations using whichModels = "top" (Rouder, Morey, Verhagen, Swagman, & Wagenmakers, 2017). The "top" option allows the user to compare a model that included all possible effects to models that exclude one particular effect. If the full model is preferred to a model without a certain effect then that is evidence in favor of the effect. The degree of evidence for or against an effect is reflected by the Bayes factor, which represents the ratio of the strength of evidence for one model over another. A Bayes factor of 1-3 is weak evidence of the preferred model, 3-20 is positive evidence, 20-150 is strong evidence and anything greater than 150 is very strong evidence over the less likely model (Raftery, 1995).

In the analyses reported here, when there is support from the Bayes factor indicating an effect, a significant *p*-value would also have been found in the standard null-hypothesis significance test.

The Bayesian analysis on response times for the switch conditions included response hand (left or right) and wrist orientation (horizontal or vertical) as the factors. There was positive evidence for an effect of orientation change (BF = 10.4) and for the interaction between hand and orientation change (BF = 10.6). There was also very strong evidence for an effect of hand change (BF > 1000). The interaction indicates that maintaining the same orientation produced a benefit only when the response hand was retained as well. This conclusion was supported by two pairwise comparisons that indicated that the orientation change effect was present only in the same-hand condition (BF >1000 for the presence of an effect in the same-hand condition, BF = 3.8 for the absence of the effect change-hand condition).

For switch trials, the average spoil rate across conditions was less than 1% and therefore no analysis was conducted. The average error rate on switch trials was 1.9%, while the average error rate on the green dot trials was 2.5%. See Figure 5 for mean error rate for each hand cue condition. A Bayesian analysis of the error rates showed strong evidence for the effect of hand change (BF = 104.3), positive evidence against an effect of orientation change (BF = 4.95), and weak evidence against an interaction (BF = 1.7)[1].

[1] Additional analyses were done on the error rates of Experiments I, II, and III using an arcsine transformation. The Bayesian analyses led to the same results without the transformation in Experiments I, and III.

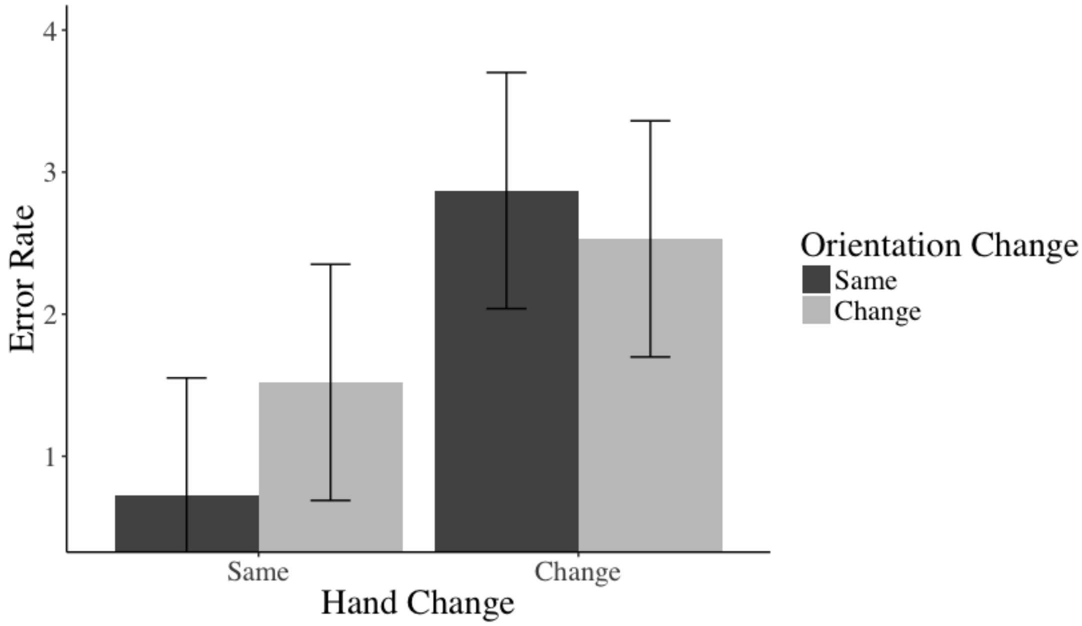

Figure 5. Mean error rates by orientation and hand change. Error bars represent 95% within-subject confidence intervals.

Discussion

Experiment I was designed to assess the possible effect of overlapping features when changing from a planned motor action to a new one. Participants prepared a grasp denoted by letter cues and then either executed the motor plan when they saw a green dot, or abandoned the motor plan and executed a new plan according to a hand cue. The results show that motor plans can transfer within hands, such that acting using the same hand as required by the original motor plan can produce a benefit, even when the orientation of the new motor plan has changed. The results also showed that there was no transfer of motor plans across hands. We take this result to imply that motor plans are limb specific. There was, however, evidence for a benefit of retaining the same wrist orientation when the response hand remained the same. We suggest that this pattern of results indicates that hand and wrist orientation components of a motor plan are integrated into a hierarchy with response hand as the dominant dimension. Within this hierarchy, a subsequent action using the same hand can benefit from the established action plan, even though wrist orientation may have changed. The hierarchical action plan, however, is not available when the new action requires a different response hand.

Experiment II

Our interpretation of the results of Experiment I might be questioned given that a different response element was assigned to each hand. It is possible that the two response elements afforded left and right responses such that a left-hand motor plan was mapped onto the left element and a right-hand motor plan was mapped onto the right element. This mapping may have artificially segregated motor plans to prevent transfer across hands. Therefore, Experiment II was a replication of Experiment I in which only one response element was used. All other aspects of Experiment I remained constant. If this alternative explanation of lack of transfer across hands is correct, we should now observe successful cross-hand transfer.

Method

Participants: 41 (33 female; median age = 21 years) right-handed undergraduate students at the University of Victoria took part in a one-hour and 15-minute scheduled appointment to gain extra credit for a registered course.

Materials: The experiment was a replication of Experiment I, with the exception of the number of response elements. In Experiment II, only one element was used for both left and right grasps (see Figure 6). The base of the response element was centered on the response device base and the direction of the horizontal protrusion of the response element was counterbalanced between participants.

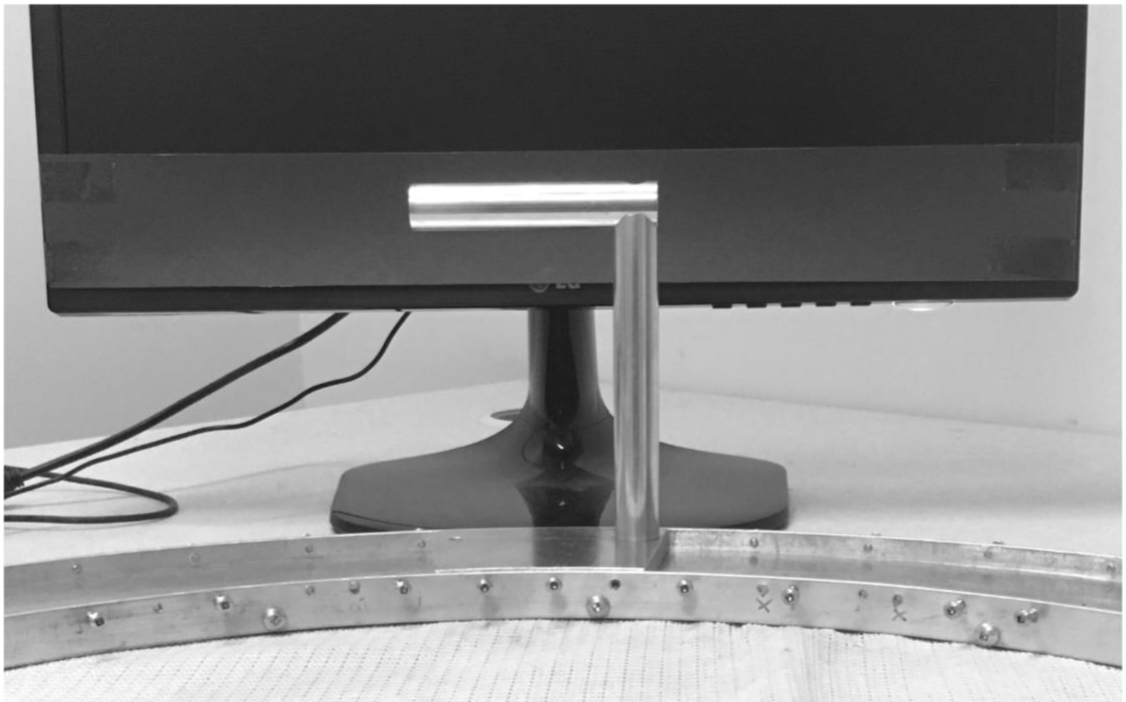

Figure 6. Example response element for Experiment II.

Design and Procedure: The design and procedure followed Experiment I, with the same balance of practice, and critical trials. However, participants were instructed to use the one response element in front of them for both the left and right grasp actions. The trials and stimuli were the same as in Experiment I.

Results

Three participants' data were excluded from the analysis due to error rates higher than 15% on the green-dot trials. Response times less than 100 ms and greater than 2,100 ms were excluded from the analysis so that no more than 0.5% (0.36%) of the data was excluded. For each participant the mean correct response time for each switch condition was computed and the means are shown in Figure 7. The green-dot trials produced a mean response time of 776 ms

(67.2% of trials were completed before the deadline), which was substantially shorter than any switch condition, again indicating that participants had prepared the letter-cued action.

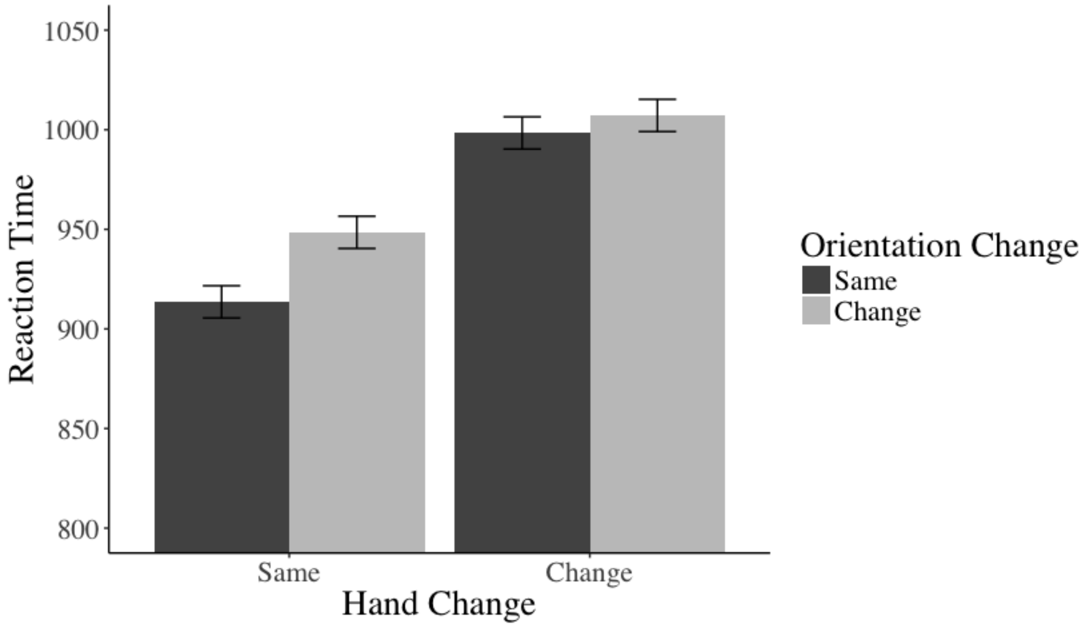

Figure 7. Response time as a function of orientation and hand change. Error bars represent with 95% within-subject confidence intervals.

The effect of hand and orientation change on response time were again evaluated by computing a Bayesian analysis. This analysis revealed very strong evidence for a hand-change effect (*BF* >1000), positive evidence for an orientation-change effect (*BF* = 14.7), and very strong evidence for an interaction (*BF* >150). As in Experiment I, the interaction indicated that the advantage of maintaining wrist orientation appeared only when the hand also remained the same (*BF* > 1000 for an effect of orientation change when responding with the same hand, but *BF* = 1.9 for no such effect when the response hand changed).

The average spoil rate was again less than 1% so no analysis was done for that measure. The average error rate when a change was required was 3.0%, while the green dot error rate was 2.6% (see Figure 8). A Bayesian analysis of the error rates indicated positive evidence against an effect of orientation (*BF* = 4.4). There was, however, very strong evidence for an effect of hand (*BF* >1000). The result of the test for an interaction was inconclusive (*BF* = 1.0)[2].

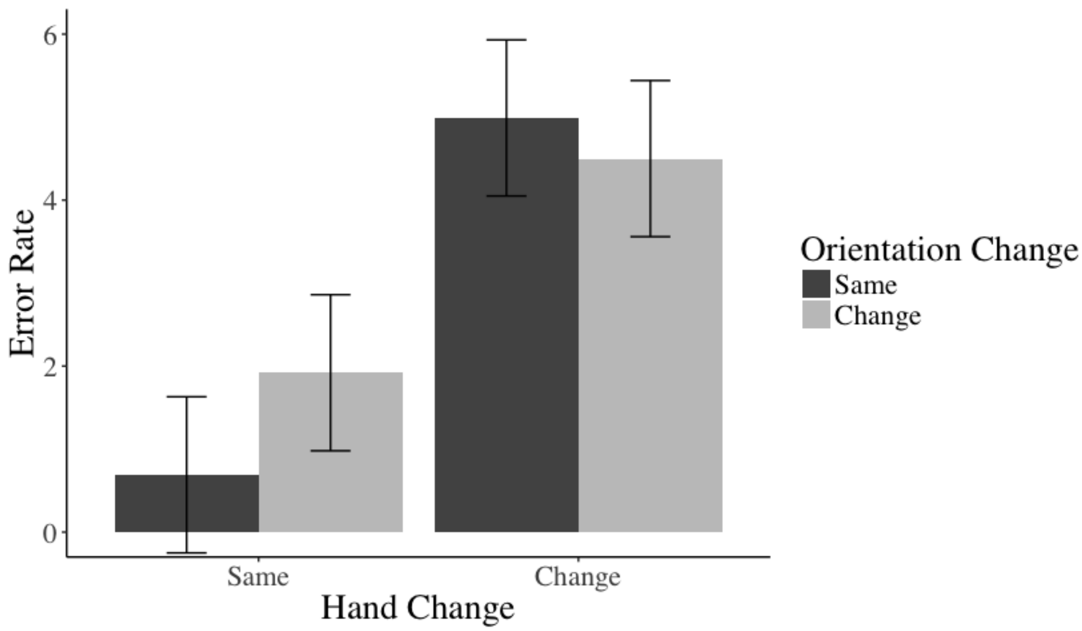

Figure 8. Mean error rate as a function of orientation and hand change. Error bars represent with 95% within-subject confidence intervals.

[2] An arcsine transformation on the error data differed from the analysis on the raw data, revealing positive evidence for an interaction (BF = 15.1) and weak evidence against an effect of orientation (BF = 1.5).

Discussion

Experiment II was a replication of Experiment I with the exception of the number of response elements used. This replication was carried out to determine whether the effects found in Experiment I were due to a limb-specific mapping to separate response elements. The results in Experiment II showed the same evidence for limb specificity of motor plans as in Experiment I. That is, there was a benefit of retaining the same response hand as well as transfer of orientation within the prepared hand, but no transfer across hands. This indicates that the findings in Experiment I are robust and are not due to the presence of two response elements.

Experiment III

In Experiment III the same two dimensions were manipulated as in the previous experiments: wrist orientation and hand change. The procedure was the same as with previous experiments with the exception of how the new action was cued. Instead of using hand cues, images of handled objects cued the new action on each trial. This method allowed us to explore whether objects would afford the same motor representations as hand cues, and whether transfer of prepared motor plans might therefore show the same pattern.

Method

Participants: 38 right-handed participants (33 female; median age = 20 years) took part in the experiment to gain additional credit for an undergraduate psychology course at the University of Victoria. Participants in this experiment did not take part in any of the previous experiments.

Materials: The same letter code cues were used as in Experiment I. However, instead of using images of hands to cue an action change, grayscale images of handled objects were used. The images were objects and tools commonly found in households, having either horizontal or vertical handles. The particular objects were chosen because of their familiarity and ability to be rendered in clear left and right versions. An image of an object was selected and then resized to its relative size with the largest object (frying pan) as the baseline. Sixteen objects were used: 8 horizontally handled objects and 8 vertically handled objects. The full set of object images is provided in the Appendix. Each image was then horizontally mirrored so that each object had a rendering with the handle on the right and a rendering with the handle on the left. This was done to ensure that there were no differences between left and right versions of the objects. The same button box and response device was used as in Experiment II.

Design and Procedure: The design for Experiment II was the same as in earlier experiments with the following exceptions. First, there was a practice block consisting of 32 trials in which the 16 objects were each presented twice, once rendered with the handle on the right and once with it on the left. Second, there was a practice block of critical trials where 24 of the critical trials were randomly selected for each participant as practice. Finally, there were 320 critical trials, 64 with green-dot cues and 256 with object cues, divided into 10 blocks with breaks in between.

The procedure was the same as in Experiment II, except that the new action was cued by the picture of a handled object instead of a hand posture.

Results

Two participants' data were excluded from the analyses. One was excluded because of experimenter error and the other because of an error rate greater than 15% on the green-dot trials. Correct responses less than 100 ms and greater than 2,200 ms were excluded so that no more than 0.5% (0.39%) of the data were lost. Response times were recorded in the same way as with the previous experiments. Average correct response time in each switch condition is shown in Figure 9.

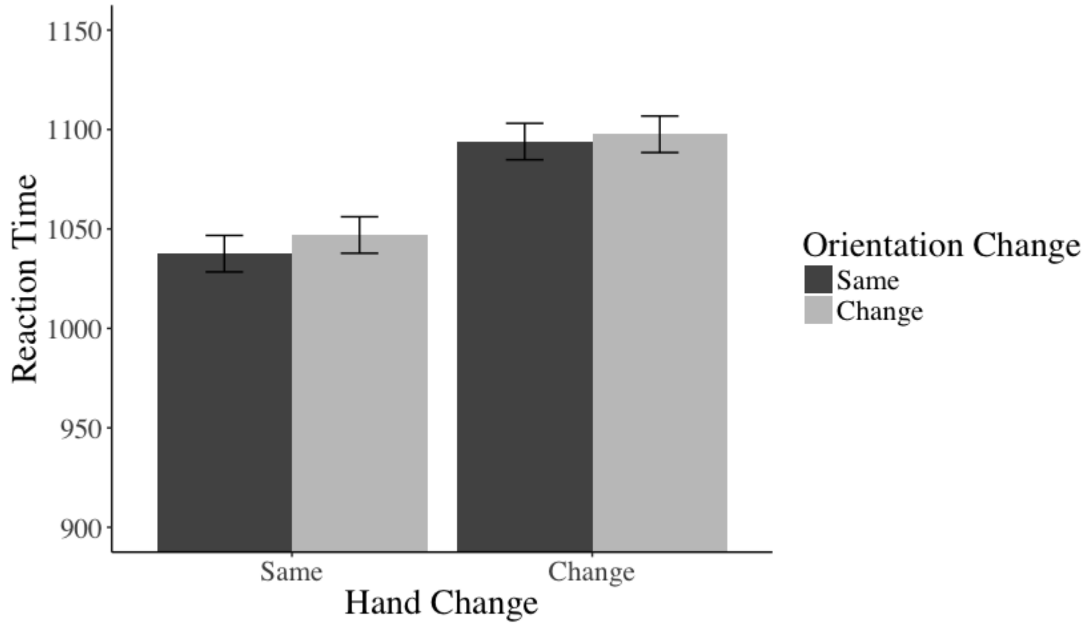

Figure 9. Response time as a function of orientation and hand. Error bars represent with 95% within-subject confidence intervals.

The green-dot trials produced a mean response time of 805 ms (65% of trials were completed before the deadline), which was much shorter than the response time on switch trials, signifying that participants had prepared the letter-cued actions. A Bayesian analysis of response time indicated very strong evidence for an effect of hand change (*BF* > 1000), weak evidence for no effect of orientation change (*BF* = 1.6) nor interaction (*BF* = 2.0).

The average spoil rate for switch conditions was less than 1% so no analysis was done for that measure. The average error rate for switch conditions was 2.3%, and the average greed dot error rate was 1.3%. See Figure 10 for mean error rates by switch condition. A Bayesian analysis of error rates indicated very strong evidence for an effect of hand change (*BF* >1000). There was positive evidence against an effect of orientation change (*BF* = 4.0) and against an interaction (*BF* = 3.9).

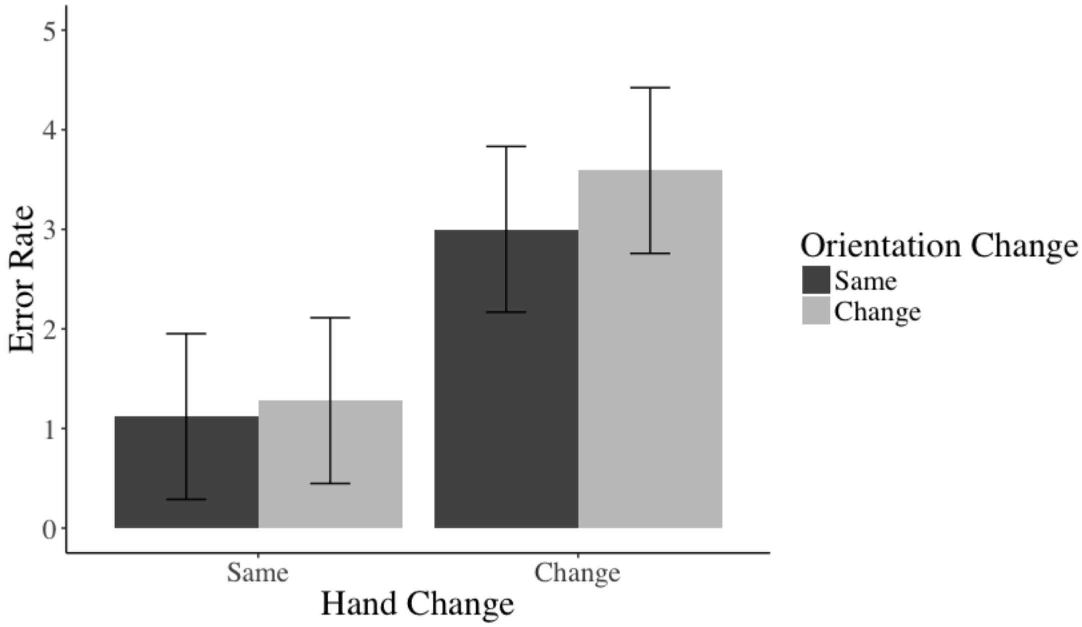

Figure 10. Mean error rate as a function of orientation and hand change. Error bars represent with 95% within-subject confidence intervals.

Discussion

The hand cues used in Experiment I and II are images of goal postures that provide a relatively direct representation of hand actions. In Experiment III, we asked whether there are fundamental differences between those action representations and the ones associated with handled objects. If handled objects evoke motor representations similar to those elicited by hand images, we would have expected to see the same results as in Experiments I and II. The results of Experiment III, however, showed only a main effect of hand change. This outcome means that when switching motor plans, only hand selection can transfer between plans, but orientation can no longer transfer, even within the same hand. We speculate that a handled object provides information about handle location more quickly than information about handle orientation.

Under these circumstances, participants will be able to take advantage of the prepared hand early during the construction of the newly cued action. Given the assumed hierarchical representation of the original motor plan, it would be possible to borrow the hand specification from that plan without necessarily also extracting the orientation component. If transfer from the original motor plan can take place only during a short period of time, then information about orientation might no longer be available when participants decode the orientation requirement from the object cue. We suggest that the longer response time of switch trials, seen in Experiment III relative to the first two experiments (1078 ms vs. 943 ms) is consistent with a minor delay in deriving the orientation parameter from the object cue.

Experiment IV

It has been proposed that identifying an object is assisted by knowledge about how one interacts with that object (Martin et al 1995;1996). If motor properties of the object are involved in identifying it, then we might expect that object naming would benefit from a related, previously planned action. In particular, there should be at least a benefit of positioning the object's handle in the same side of space as the response hand in the prepared motor plan. In Experiment IV we used the same stimuli as Experiment III. However, instead of acting on the object cue, participants were required to name the handled object.

Method

Participants: 38 University of Victoria undergraduate students (30 female; median age = 20 years) took part in the experiment to earn extra credit for a psychology course. All participants were right-handed.

Materials and Design: The same stimuli and design from Experiment III were used.

Procedure: Participants were again tested individually using a G3 Macintosh computer during a one-hour scheduled appointment. The participant wore a microphone headset that detected vocal responses and signaled the onset of a response to the computer. The experimenter sat across the desk with a Mac computer to instruct the participant and mark each critical trial as correct, incorrect, or as a spoil. The same criteria for correct and incorrect categories were used as in previous experiments. However, in addition to the criteria for a spoil trial, a trial was marked a spoil if the participant said something before naming the object that triggered the microphone input. Before the experiment began, participants went through a microphone test to ensure that their voice could be picked up by the microphone. Participants were instructed to talk into the microphone as if they were talking at an audible level for the experimenter to hear. They were also instructed not to say anything before naming the stimuli as the microphone would pick that up (i.e., uhm, ahh). Participants were told to name the cue that showed up on the screen (i.e., A, B, C, blue, pink) and that the stimulus would disappear when the microphone picked up their voice. If the stimulus stayed on the screen participants were told that they should repeat what they said louder until it did disappear. If this happened, after all the test trials were done and the microphone test was completed, the experimenter would change the sensitivity level, to no lower than 5 on the sensitivity scale set by the computer program (standard = 7), and the microphone test would be repeated until the participant could trigger the stimulus to disappear on the first attempt at naming it. This was done to ensure that during the experiment there would be no issues with microphone input. The experimental portion began with the same practice trials of letter cues as in Experiment I, with the exception that the deadline was set to 500 ms because only the lift-off component of the action was recorded. Once the letter cue practice was completed participants were then shown printed photos of the handled object stimuli by the experimenter to ensure they were familiar with the names of the objects. Before participants began to practice trials with handled objects, they were instructed to not say anything before naming the object so as to not trigger the microphone input. If a participant was unaware of the object's name, he/she was instructed to guess and the experimenter would correct him/her if necessary. The name of the object was provided to participants as feedback during practice trials, but not during the critical trials. There was then a handled-object practice set wherein participants saw all images of the handled objects twice, once with the handle on each side of space, and as soon as they recognized the object, they were to name it. The experimenter would then mark the response as correct, incorrect, or spoil to start a new trial. Prior to the critical trials, participants received 24 randomly selected critical trials for practice. The critical trials ran the same as in Experiment III except that participants named the pictured object as quickly and accurately as possible.

Results

Two participants were excluded from the analyses due to experimenter marking error. Correct responses less than 100 ms and greater than 2,300 ms were excluded so that no more than 0.5% (0.43%) of the data was lost. Response times were defined as the time taken from the onset of the object cue to detection of a vocal response. Only the lift-off component of the response times on green-dot trials could be recorded because the program capabilities would not allow for inputs from both the response device and microphone channels. The mean lift-off time for green-dot trials was very brief, just 344 ms (72.3% of trials were completed before the deadline), suggesting that observers had prepared the letter-cued actions. Moreover, there were no errors on these trials. The mean correct response object-naming times for each switch condition are shown in Figure 11. The effects of changing hand and orientation on correct response time were evaluated by computing a Bayesian analysis. There was positive evidence favouring the null over each of the effects (*BF*s > 3.0). Because the error rates in the naming task were less than 1% (green dot error rate was 0%), no analysis of those data was conducted.

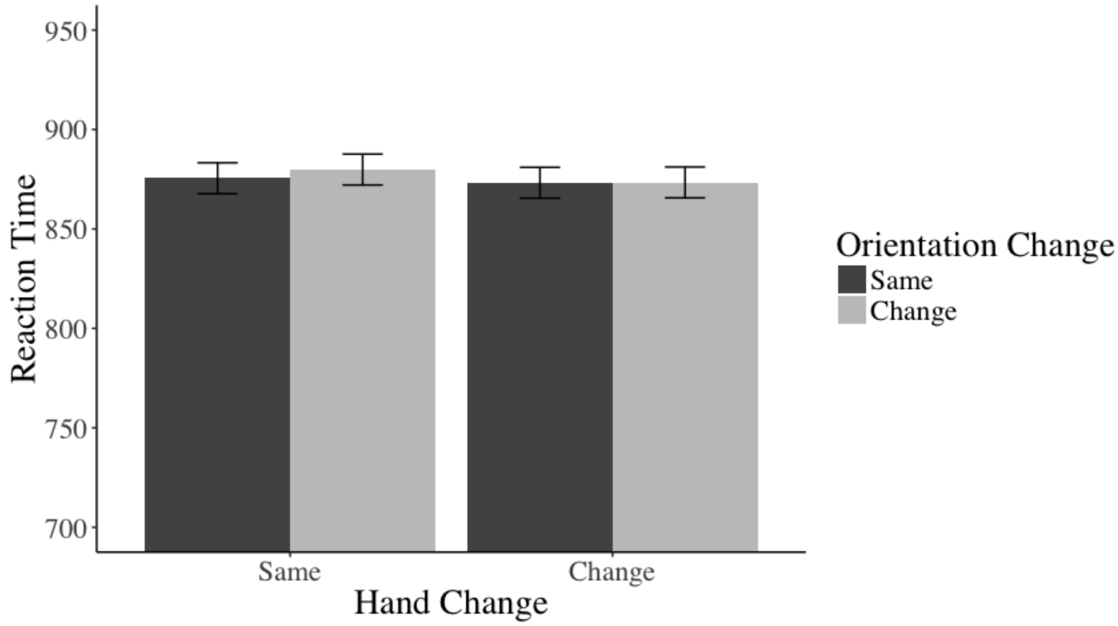

Figure 11. Response time as a function of orientation and hand change. Error bars represent 95% within-subject confidence intervals.

The average spoil rate for the naming task was 2.11%. See Figure 12 for mean spoil rates for each switch condition. A Bayesian analysis of spoil rates showed positive evidence favouring the null over each of the effects (*BF* > 3.0)[3].

[3] An arcsine transformation was done on the raw data of the spoil rates. The results of the Bayesian analysis differ in that there is positive evidence against an interaction (BF=4.1).

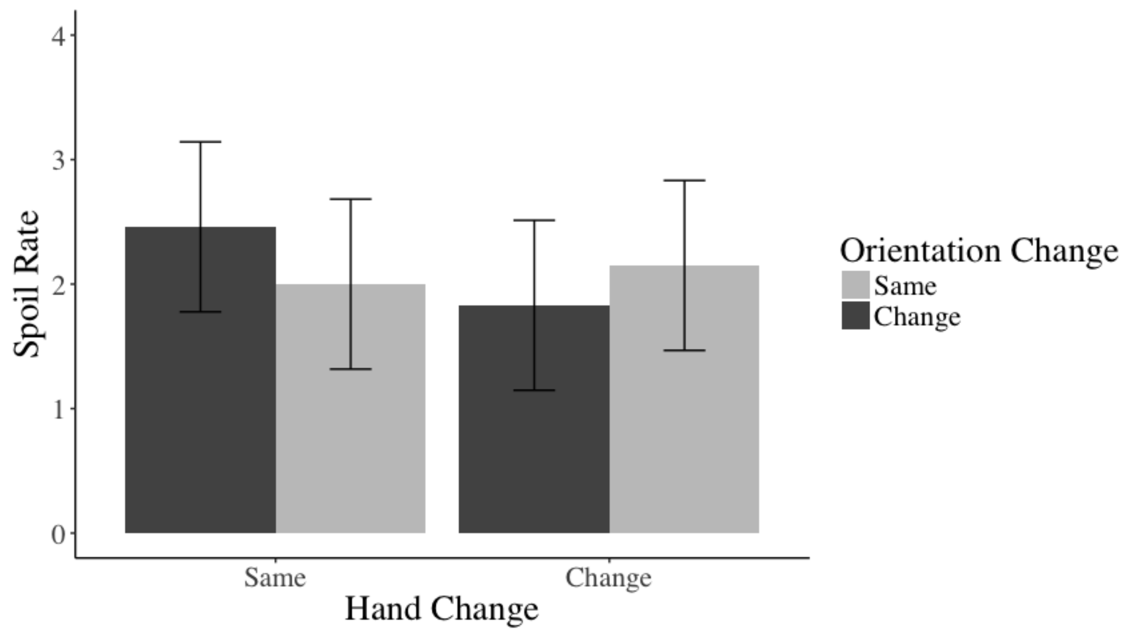

Figure 12. Spoil rate as a function of orientation and hand change. Error bars represent 95% within-subject confidence intervals.

Discussion

Experiment IV was a replication of Experiment III, with the exception that participants had to name the handled objects instead of making the grasp afforded by the object. The goal was to determine whether the same motor representations that support a prepared action would facilitate the identification of an object whose handle shared spatial features with that action. The results show no indication that any feature of the prepared action assisted with the naming task. This result suggests that if any action representations are evoked by identifying objects, they do not have components in common with the prepared actions that we used here.

General Discussion

The results from Experiments I and II provide evidence that transfer of feature information is not only found between completed actions (Jax & Rosenbaum, 2007; Valyear & Frey, 2014; Schütz & Schack, 2015), but also between a motor plan that is cancelled before execution and a new action. In line with Schütz and Schack's (2015) results, in Experiment I we found that the hand feature could transfer between motor plans, but that wrist orientation could transfer only when the same hand was used. We claim that these results indicate a hierarchical integration of hand action features with hand selection dominating wrist orientation. Within this arrangement, transfer of the orientation feature depends on maintaining the same hand selection across motor plans. If hand selection changes between motor plans, then the orientation feature will not be available. Based on Schütz and Schack's (2015) extrinsic target coordinate account of why Jax and Rosenbaum (2007) showed transfer of curved trajectory across hands, we considered the possibility that the absence of cross-hand transfer in our Experiment I was due to a mapping between each hand and unique response element. Using a single response element in Experiment II, we replicated the findings of Experiment I. In contrast to our results in Experiments I and II, Bub, Masson and Kumar (2017) found independent effects of dimensions when superimposing an image of a hand onto a picture of a handled object and requiring participants to make a reach-and-grasp action associated with the hand. The effects were independent in that the orientation information could transfer even when the hand was different than the hand cued by the handled object. In Experiments I and II, participants were required to prepared the letter-cued action such that they were fully ready to make the action, whereas in the Bub et al. study, the coding of the action representation associated with the handled object appears to have been abstract, so that the dimensions were independent and not hierarchically integrated, contrary to what we saw in our Experiments I and II.

It is possible that transfer of hands could be present in our experiment but not reflected in the response time measure. Schütz and Schack (2015) proposed that measuring effects in Cartesian space, as done with the trajectory analysis by Jax and Rosenbaum (2007), might capture effects that cannot be detected by response time measures. It is plausible that the transfer of wrist orientation between motor plans when the response hand changes is present when observing effects in Cartesian space. In future work, we plan to use our experimental task to determine whether subtle differences in hand trajectory might be produced by transferring wrist orientation across a change in response hand. These effects could be detected by measuring hand kinematics. For example, a vertical wrist orientation carried across a change in response hand could result in an earlier rotation of the wrist into a vertical position during flight. This type of carryover effect may not be apparent in response time data, even though it might be observed in the hand trajectory.

Experiment III was designed to expand the understanding of the differences and similarities between the motor representation evoked by objects and by hand cues. Functional imaging data has shown that both images of hands and graspable objects activate regions of the cortex responsible for planning movement (Mahon, 2013: Martin et al. 1995; Martin et al.1996). Our results indicate that the motor plan dictated by the object cue made use of the previous motor plan's hand selection. There was no indication that any use was made of wrist orientation. Our proposal is that the object's handle location and it's handle orientation follow two different time courses, with handle location available much sooner. This timing difference could be responsible for the restricted transfer seen in Experiment III.

After having established results that show some degree of transfer of motor plans, in Experiment IV we examined how a planned hand action might influence object naming. Literature suggests that naming an object is more difficult when the object's handle is on the same side of space as the participant's hand that is being used to carry out a simple task (Witt et al., 2010). Additionally, Bub et al. (2013) found that time required to name a handled object was modulated by the relationship between the location and orientation of the object's handle and features of hand actions held in working memory. Our results from Experiment IV showed no transfer of hand or orientation from a cancelled motor plan to naming an object. It is important to note, however, that the task in the Bub et al. (2013) experiments required participants to encode the target hand actions in working memory for later execution. This demand may have resulted in an abstract representation of action features that is quite different from the representation of a motor plan that is to be executed immediately. There may be little overlap between representations of hand actions associated with objects and features of a motor plan that is about to be executed. In a future experiment we plan to induce participants to encode to-be-named objects in a way that evokes action representations that more closely resemble those used in preparing an immediate action. The experiment would be a replication of Experiment IV in which a colour cue is presented with each handled object, whereby one colour indicates that participants should name the object, but the other colour signifies that the participant should perform the action implied by the object. By randomly switching between colour cues, participants are likely to be induced to orient toward each object in a manner that invites the construction of relevant motor plans. Under these circumstances a different type of motor representation may be elicited even on naming trials, producing measurable transfer from the original motor plan. A result such as this would reinforce the primary conclusion from the present experiments, namely, that motor representations appear capable of taking on one of a number of possible forms that eventually dictate the extent to which their components may transfer to subsequent actions.

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Appendix

Images of handled objects used in Experiments III and IV

Horizontally handled objects

Vertically handled objects